

# The effect of CT angiography and venous couplers on surgery duration in microvascular breast reconstruction: a single operator's experience

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**Background:** The use of CT angiography (CTA) or venous couplers (VCs) has led to shorter operative times in free flap breast reconstruction (FFBR). However, there are no reports on the effect of these two interventions relative to each other or combined.

**Methods:** Abdominal based FFBRs performed by a single surgeon before introduction of either intervention were compared to those with VC only, and those after the addition of CTA to VCs (CT-VC). Operative time was defined as from “knife-to-skin” to insertion of the last stitch.

**Results:** One hundred and twenty patients; 40 without intervention (WI), 40 with VC, and 40 with CT-VC. Introduction of VCs did not significantly reduce operative time compared to WI ( $P=0.73$ ). However, patients in the CT-VC group had significantly shorter operations *vs.* WI (472 *vs.* 586 min,  $P<0.00001$ ) and *vs.* VC alone (472 *vs.* 572 min,  $P=0.0006$ ). Similarly, introduction of each intervention showed a stepwise decrease in ischaemia time (WI *vs.* VC: 100 *vs.* 89 min,  $P=0.0106$ ; VC *vs.* CT-VC: 89 *vs.* 80 min,  $P=0.0307$ ; WI *vs.* CT-VC: 100 *vs.* 80 min,  $P<0.00001$ ).

**Conclusions:** Combination of CTA and VC significantly reduced operative and ischaemic times for FFBR; this was predominantly due to use of CTA. CTA mitigates the surgical learning curve as demonstrated by shorter operating times via providing a vascular anatomy roadmap, thus facilitating flap harvest.

**Keywords:** Computed tomography angiography (CTA); deep inferior epigastric perforator flap (DIEP flap); microvascular breast reconstruction; operative time; venous coupler (VC)

Submitted Jul 06, 2018. Accepted for publication Jul 31, 2018.

doi: 10.21037/gs.2018.07.11

**View this article at:** <http://dx.doi.org/10.21037/gs.2018.07.11>

## Introduction

The deep inferior epigastric perforator (DIEP) flap is now considered the gold standard in autologous breast

reconstruction (1,2). However, well-executed harvesting and successful performance of DIEP flap surgery requires considerable expertise (3), with careful preoperative and intraoperative decision-making being essential.

**Table 1** Previous studies of venous couplers or CTAs documenting surgical duration of free flap breast reconstruction

Study	Year	Number of patients [flaps]	VC/CTA	Operative time reduction	Other comments
Masia <i>et al.</i> (19)	2006	66	CTA	100 min	Pioneering demonstration of CTA utility
Rozen <i>et al.</i> (20)	2008	88 [104]	CTA	10 min (unilateral) 77 min (bilateral) (NS)	Decreased flap loss, donor site morbidity and operative stress for surgeons
Smit <i>et al.</i> (21)	2009	[138]	CTA	90 min	Trending to reduced complication rate
Casey III <i>et al.</i> (22)	2009	213 [287]	CTA	89 min (unilateral) 142 min (bilateral)	Significant decrease in abdominal bulges and increase in number of perforators used
Masia <i>et al.</i> (4)	2009	321	CTA	Reduced: min unspecified	Significant reduction in postop complications
Minqiang <i>et al.</i> (23)	2009	44	CTA	96 min (flap harvest time)	Significant reduction in flap complication rate
Uppal <i>et al.</i> (24)	2009	26	CTA	76 min	(No significance calculated)
Ghattaura <i>et al.</i> (25)	2010	100	CTA	77 min	Reduction only in unilateral flaps. Increased perforators in CTA group & reduced hernia rates
Rozen <i>et al.</i> (26)	2010	1,000 [2,500]	VC	18 min (anastomotic time)	Included arterial anastomoses
Tong <i>et al.</i> (27)	2012	69 [102]	CTA	140 min (unilateral) and 117 min (bilateral)	Incidentalomas found in 36% of group
Malhotra <i>et al.</i> (16)	2013	100	CTA	85 min	Reduced intraoperative blood loss and shorter mean inpatient stay
Fitzgerald O'Connor <i>et al.</i> (17)	2016	540 [632]	CTA	13 min (flap harvest time)	Reduced flap harvest time Reduced complication rate
Vargas <i>et al.</i> (28)	2016	778 [1,110]	CTA	No change	Lower ischaemic complication rate did not reach statistical significance (P=0.058)
Fitzgerald O'Connor <i>et al.</i> (15)	2016	1,064 [1,206]	VC	12 min (anastomotic time)	Reduced return to theatre & reduced failure rate

CTA, computed tomography angiography; VC, venous coupler; NS, not significant.

Preoperatively, study of the donor vessels and abdominal wall vascular anatomy has been shown to be helpful in reducing operative times and aiding successful free tissue transfer (4-6). The major abdominal wall vascular perforators and the courses of the main branches of the deep inferior epigastric vessels can be accurately identified with computed tomography angiography (CTA), magnetic resonance angiography (MRA) or Doppler ultrasonography (3,5,7,8). Studies have shown that use of such preoperative road maps can reduce operative times (6,9).

Microvascular anastomosis is one of the critical intraoperative steps of free flap surgery. Most consider the venous anastomosis paramount because of the increased propensity for venous thrombosis with venous insufficiency being the most common cause for return to theatre (10-12). The venous coupler (VC)

has been shown to be a quick and reliable method for re-establishing venous drainage with reduced anastomotic failure when compared to hand sewn vessels (13-15).

However, despite the many reports of reduced operative times with the use of CTA (4,16,17) or VCs (5,18) (*Table 1*), there are none that have compared the effect of these two interventions relative to each other. The principal aim of this study was therefore to review the effect of VCs alongside CTA on the operative times of free flap breast reconstruction (FFBR).

## Methods

All free flap breast reconstructions performed by a single plastic surgeon (CMM) at a tertiary university hospital breast

**Table 2** Summary of the clinical data of the three groups (without intervention, venous coupler only, CTA with venous coupler)

Clinical variable	Without intervention (WI)	Venous coupler only (VC)	CTA & venous coupler (CT-VC)
Number of patients	40	40	40
Age (mean, range)	51.5 (r: 36–67)	49.4 (r: 34–65)	49.7 (r: 34–68)
Unilateral flaps	35	33	29
Bilateral flaps	5	7	11
Immediate flaps	28	31	34
Delayed flaps	17	16	17
Total flaps	45	47	51
Total operative time <sup>†</sup> /min	585.5 (r: 470–840)	571.6 (r: 364–780)	472.1 (r: 270–700)
Ischaemia time <sup>†</sup> /min	99.7 (r: 42–127)	88.9 (r: 38–137)	80.4 (r: 52–122)
Median coupler size, mm	–	3.0	3.0
Anastomotic revisions	0	2 V	1 V, 1 A
Re-explorations	0	3	3

<sup>†</sup>, denotes statistical significance. V, venous; A, arterial.

cancer referral centre between August 2008 and February 2014 were included in this retrospective cohort study, to ensure that all patients before and after the introduction of CTA (November 2011) were included. Bipedicled free flaps (n=26) were excluded as was one patient with incomplete data. Patients with neither intervention were compared to those who received only VCs (introduced in June 2010) and those with both interventions. It was not possible to study the effect of CTA without VCs as all CTA patients had had VCs. Patients were identified from a prospectively collected free flap database and the senior author's free flap logbook. Operations were performed by two teams (one consultant and two assistant surgeons) so recipient vessel exposure was performed at the same time as flap harvest. Details were collected on patient demographics, flap type, ischaemia time, total operative time, number of veins used and coupler size. Flap harvest time was not recorded.

The purpose of including only a single surgeon's cases was three-fold, firstly to eliminate inter-operator variability, secondly to standardise the internal mammary vessel exposure technique (all total rib preservation) and thirdly to standardise the method of venous anastomoses (exclusive coupler use after June 2010). Operative time was defined as from “knife-to-skin” to insertion of the last stitch (as documented independently by the nursing staff). The surgeon has been in practice for over 10 years so a surgical learning curve is unlikely to be in effect.

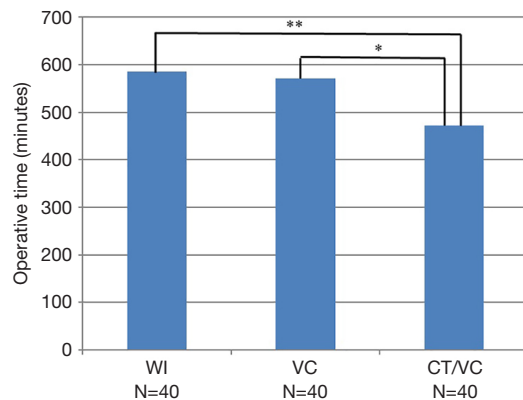
A literature search was conducted through PubMed and Web of Science with the terms, “computed tomography angiography”, “breast reconstruction”, “venous coupler”, “operative duration”, “anastomotic time” and “venous anastomoses”. All relevant reports were included (*Table 1*). Data analysis was completed with IBM SPSS Software Version 24.0 (IBM Corp, 2017. IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp). Data were analysed with the Kolmogorov-Smirnov test and were not found to follow a normal distribution. Therefore, differences in operative and ischaemia times between the groups were evaluated with the nonparametric Mann-Whitney U test. Statistical significance was determined by a value of  $P \leq 0.05$ .

## Results

One hundred and twenty patients were divided into three groups; the last 40 patients without intervention (WI), the 40 patients that had received VC only, and the first 40 patients who received CTA with venous coupler (CT-VC). The mean ages were comparable; *Table 2* shows characteristics of all three patient groups.

A total of 143 flaps in 120 patients (mean age = 50.5 years; range, 28–68) were included in this study. Ninety-seven patients received unilateral flaps whilst 23 patients had bilateral flaps. Two thirds (65%) of the flaps

were performed in the immediate setting at the time of mastectomy. The mean total operative time for all patients was 542.6 minutes (range, 270–840) with a mean ischaemic time of 89.1 minutes (range, 38–137).



**Figure 1** Operative times for the three groups. \*, denotes  $P=0.0002$ . \*\*, denotes  $P<0.00001$ . There was no significant difference with the use of venous couplers only versus no intervention. WI, without intervention; VC, venous coupler only; CT-VC, CTA and venous coupler.

### Duration of surgery

The mean operative times in minutes were 585.5 ( $r=470-840$ ), 571.6 ( $r=364-780$ ) and 472.1 ( $r=270-700$ ) for WI, VC and CT-VC, respectively (Figure 1, Table 3). Introduction of couplers did not significantly reduce the operative time compared to no intervention (572 *vs.* 586 min,  $P=0.5306$ ). However, patients with both interventions (CT-VC) had significantly shorter operative times versus WI by 114 minutes (472.1 *vs.* 585.5 min,  $P<0.00001$ ). This pattern remained the same when the group was divided in unilateral, bilateral, immediate and delayed flaps (Tables 3,4).

Interestingly, the CT-VC group had a significantly reduced operative time compared to the VC group by 100 minutes (472.1 *vs.* 571.6 min,  $P=0.0002$ ), implying that the main factor in the reduction of surgical duration was the introduction of CTA (Figure 1, Table 3). Although this trend was mirrored in unilateral and delayed flaps ( $P<0.00001$  and  $P=0.0139$ , respectively), no significance was noted when comparing the VC group with CT-VC in bilateral or immediate flaps ( $P<0.1141$  and  $P=0.9920$ , respectively). Figure 2A shows a coronal CTA image of the anterior abdominal wall vessels. Figure 2B shows the corresponding transverse CTA image of the same.

**Table 3** Operative time of flaps

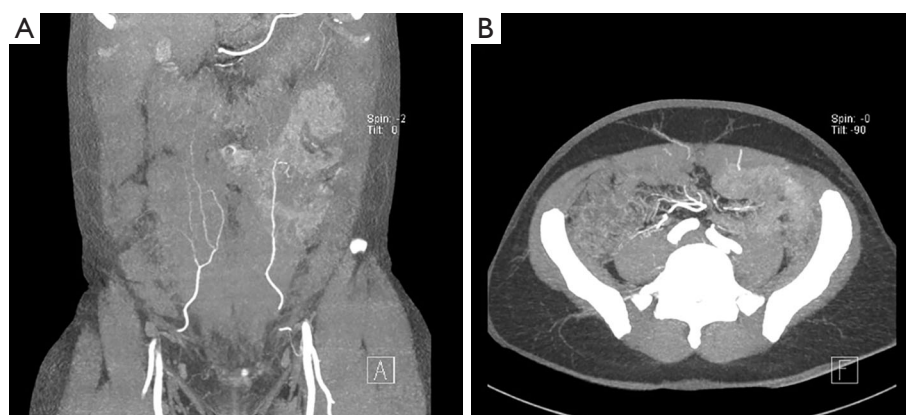
Flap category	Without intervention (WI)	Venous coupler only (VC)	CTA & venous coupler (CT-VC)
Unilateral <sup>†</sup> /min	562 (r: 470–735)	547 (r: 364–720)	419 (r: 270–620)
Bilateral <sup>†</sup> /min	747 (r: 675–840)	676 (r: 540–780)	612 (r: 540–700)
Immediate flap <sup>†</sup> /min	561 (r: 470–660)	565 (r: 364–720)	437 (r: 270–620)
Delayed flap <sup>†</sup> /min	579 (r: 480–735)	530 (r: 420–640)	414 (r: 274–480)
Total <sup>†</sup> /min	585.5 (r: 470–840)	571.6 (r: 364–780)	472.1 (r: 270–700)

<sup>†</sup>, Denotes statistical significance.

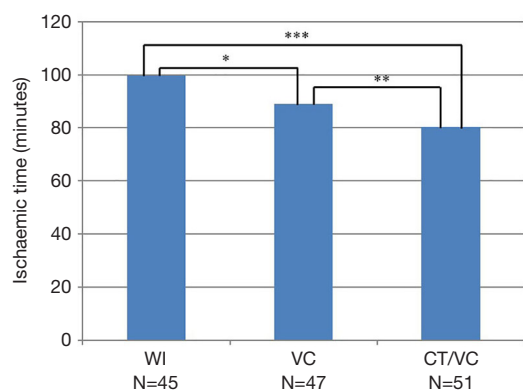
**Table 4** Statistical comparison for the three groups (P values) with respect to operative and ischaemia times

Time parameter	WI vs. VC	WI vs. CT-VC	VC vs. CT-VC
Unilateral operative time	0.6312	<0.00001	<0.00001
Bilateral operative time	0.2891	0.0065	0.1141
Total operative time	0.7263	<0.00001	0.0006
Immediate flap operative time	0.5892	0.0004	0.9920
Delayed flap operative time	0.1556	0.0009	0.0139
Ischaemia time	0.0088	<0.00001	0.0193

WI, without intervention; VC, venous coupler only; CT-VC, CTA and venous coupler.



**Figure 2** Representative CT angiograms. (A) A coronal computed tomography angiography (CTA) image of lower abdominal wall vessels showing a Moon and Taylor type II DIEA anatomy on the right and a type I on the left; (B) a corresponding transverse CTA image of the same showing a major/predominant perforator on the right with extensive arborisation within the adipose tissue.



**Figure 3** Ischaemic times for the three patient groups. There is a stepwise decrease with the addition of each new intervention. \*, denotes  $P=0.0106$ . \*\*, denotes  $P=0.0307$ . \*\*\*, denotes  $P<0.00001$ . WI, without intervention; VC, venous coupler only; CT-VC, CTA and venous coupler.

### Ischaemia time

The introduction of each intervention showed a stepwise decrease in ischaemia time (Table 2, Figure 3). The use of both modalities significantly reduced the ischaemia time from 100 to 80 minutes when compared to WI (CT-VC *vs.* WI,  $P<0.00001$ ). Similarly, CT-VC decreased ischaemia time compared to VC alone (80 *vs.* 89 minutes,  $P=0.0307$ ). There was also a significant difference between the ischaemia times of VC patients versus those with no intervention (89 *vs.* 100 minutes,  $P=0.0106$ , Table 4).

### Chronological analysis

The flaps were analysed within each category of WI, VC and CT-VC, to assess differences in unilateral flap operative and ischaemia times due to chronology. There was insufficient sample size to perform this analysis on bilateral flaps. Each category was equally divided into two, dependent on their timeline, resulting in “early” and “late” groups for each of the three categories. Results are shown in Table 5.

### Flap survival

All flap transfers were successful and there was no significant difference in the numbers of flaps requiring re-exploration ( $P=0.2356$ ) or redo of venous anastomoses ( $P=0.3868$ ).

Figure 4 and Table 6 show the distribution of coupler sizes in the VC and CT-VC groups. A greater majority of venous couplers were size 3.0 mm or larger in the CT-VC group (68%) than VC group (53%) ( $P=0.1317$ ). The median size in VC was 3.0 mm and was 3.0 mm in CT-VC. Figure 5 shows an intraoperative image of a VC.

### Discussion

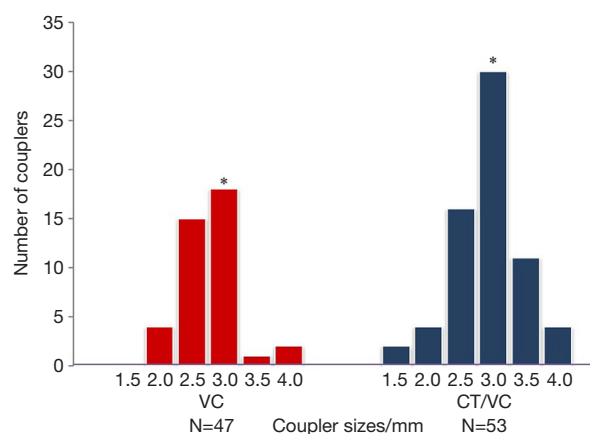
Although there are numerous reports of the independent benefits of CTA and VC on operative times (4,9,15-17), there have been no studies of effects of VCs alone versus combined with CTA. Our study has demonstrated that CTA is associated with significantly reduced operative time



**Table 5** Chronology analysis of median unilateral operative and ischaemia times in all three groups

Time parameter	WI		VC		CT-VC	
	Early	Late	Early	Late	Early	Late
Unilateral flap operative time/min	500	600*	570	530**	440	361***
Ischaemia time/min	100	101	94	90	78	76***

\*, P=0.0005; \*\*, P=0.0477; \*\*\*, P=0.0088. WI, without intervention; VC, venous coupler only; CT-VC, CTA and venous coupler.



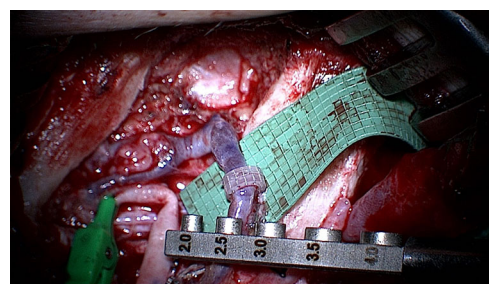
**Figure 4** Distribution of coupler sizes in VC (venous coupler only), and CT-VC (CTA and venous couplers). There is a similar distribution of size of coupler in each group. \*, denotes median size. Some patients had more than one venous anastomosis hence the difference in the numbers of patients (40 in each group) and numbers of couplers used (shown above).

in combination with VCs. The combination shortened the total operating time by almost two hours (114 minutes) compared to no intervention. However, detailed analysis revealed that this decrease was largely due to CTA effect (100 out of the 114-minute reduction in operative time).

Our findings in this study are similar to other reports regarding CTA which have shown reduced operative times ranging from 10 to 140 minutes (4,15-17). This undoubtedly is because it facilitates surgery by providing a preoperative surgical road-map. CTA allows preoperative identification of the most suitable perforators, elaboration on perforator anatomy (location described with reference to the umbilicus, and delineation of the vessel paths including tortuosity and intramuscular course) (30). Thus, an operative “game plan” can be made before surgery. Additionally, it does not involve learning a new surgical technique unlike the use of the coupler and so there is no intraoperative surgical learning curve.

**Table 6** Frequency of coupler sizes used in the two coupler groups

Size (mm)	VC group (%)	CT-VC group (%)
1.5	0 (0.0)	1 (1.9)
2.0	4 (8.5)	2 (3.8)
2.5	18 (38.3)	14 (26.4)
3.0	21 (44.7)	25 (47.2)
3.5	2 (4.3)	8 (15.1)
4.0	2 (4.3)	3 (5.7)



**Figure 5** An intraoperative view of a venous coupler sizer. A 2.5 mm venous coupler following completion of a retrograde venous anastomosis between the IMV and the DIEV with the green visibility background used to improve the contrast. The artery is just about to be anastomosed. Both anastomoses were performed in the third interspace following our total rib preservation technique of internal mammary vessel exposure (29).

The changes in the ischaemia times mirrored those in the total operative times although CTA appeared to have a greater impact. This was a surprising finding as CT angiography (unlike the venous coupler) does not have a direct impact on the technical aspects of the microanastomosis. One explanation for this could be reduced fatigue and increased confidence in the surgeon due to quicker flap harvest afforded by the CTA allowing a more predictable harvest and an earlier start to the microsurgery

when the surgeon is “fresher”. Another explanation is that surgical experience has a positive influence on surgery duration. All operations were conducted by a single operator with more than 10 years in practice, who conducts over 30 free flap breast reconstructions each year. However, there may be still be a learning curve in effect, resulting in a reduction in ischaemia times with time regardless of the intervention. This is however, highly unlikely after 10 years.

In our study, VCs reduced total operative time by 14 minutes, Fitzgerald *et al.* had similar findings in their study with 12 minutes reduction in anastomotic time which was significant (15,17). However, we acknowledge that the VC use requires adoption of a new surgical technique by the surgeon and thus any reductions in the operative time may well have been ‘averaged out’ by the learning curve (31,32). This is supported by the chronological analysis which demonstrated a significant reduction in operative time for unilateral flaps in the VC early versus VC late. Thus, implying that as the surgeon became more experienced in this new technique, operations became shorter and this effect extended into the CTA introduction period. The lack of statistical significance in the observed reduction of operative time with VCs versus the no intervention group could also be attributed to the small sample size and the “relatively short” time that the VC intervention was employed before CTA was introduced (17 months). Interestingly, the superior effect of CTA compared to VCs appears to be absent in bilateral and immediate flaps. This may reflect the impact of facilitation by CTA which allows the flap to be raised before the mastectomy is completed so flap harvest is no longer the rate-limiting step in immediate flaps. Bilateral reconstruction, which includes an immediate flap, is similarly affected.

Small reductions in operative time in isolation may not be significant but, as this study has shown, when combined with other interventions can amount to significant effects. Perhaps the true benefit of the coupler is not in decreasing ischaemia times but reducing adverse venous events, which lead to potential flap failure or fat necrosis (15,18). In fact, our study showed with the introduction of CTA the average VC size increased. This may well be because the senior surgeon became more experienced with the technique and more confident in using larger sizes, the advantage of this being that for each 0.5 mm increment in coupler diameter there is a four-fold increase in venous flow.

Unlike previous reports (15), our study was confined to a single operator in order to eliminate inter-operator variability and also to standardise the recipient vessel

exposure to the total rib preservation technique which has already been shown to reduce operative times with or without coupler use (29,33). Although trainee surgeons were also involved in the operations, the observations above relating to coupler use, CTA effect and combination still hold true.

In free flap breast reconstruction (FFBR), the ultimate goal is successful flap transfer with minimal complications to the patient, in order to shorten post-operative recovery and improve patient outcomes. Shorter anaesthetic and operative times have been shown to reduce post-operative recovery time and improve the overall patient experience (16,34). In addition, the cost saving implications are considerable. Some studies report costs utility savings as high as \$3,179, a gain in quality adjusted life-years of 0.25 (9), compared to the \$650 cost of CTA (9), and £169.50 cost for a VC (15). The cost of use of an operating theatre is estimated at £14/minute (15) so potential savings are £1,109.60 and £25.10 for CTA and VC, respectively. Hence, the expense of CTA and VCs is compensated by a reduction in total operating times, theatre utilisation, staffing and surgical waiting lists. Therefore, use of CTA and VCs has clear positive resource implications.

Although, there are multiple human and operational factors that may influence operative duration, the plastic surgery team used in all operations are experienced and complete on average two flaps per week. Thus, the results are unlikely to be affected by efficiency factors.

## Conclusions

This is the first study which demonstrates the combined effect of both CTA and VCs in significantly reducing operative and ischaemia times for FFBR; the decrease being predominantly associated with use of CTA. We believe the reduction in operative time (by almost 2 hours) is because CTA, unlike VC use, facilitates surgery without a surgical learning curve and assists in surgical planning by providing a useful roadmap of the perforator vessels. Strong proponents of these two modalities would advocate their combined use for microvascular breast reconstruction as shorter operative times have clinical benefits for the patient. Surgical experience may also play a role in reducing surgery duration.

## Acknowledgements

This work was supported by Mr Amer Durrani, Consultant Plastic Surgeon, who introduced the use of couplers to the

Cambridge University Hospital in 2010.

## Footnote

*Conflicts of Interest:* The authors have no conflicts of interest to declare.

*Ethical Statement:* This study was part of a quality improvement assessment and an ongoing departmental free flap audit. Audits and Quality Improvement Assessments are part of a larger framework for Clinical Governance, whereby National Health Service (NHS) organizations are accountable for continuously improving the quality of their services and safeguarding high standards. Clinical governance (inclusive of audits and quality improvement assessments) is compulsory within the NHS. No ethical committee approval is therefore needed. Under the Caldicott Principles, non-identifiable patient data can be collected, stored and used for purpose of audit without individual patient consent. Additionally, all data were collected retrospectively from hospital medical records. Therefore, individual patient consent was not required for this study. Subjects in clinical photographs gave informed consent for use of images in journal publication.

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**Cite this article as:** Ngaage LM, Oni G, Di Pace B, Hamed RR, Fopp L, Koo BC, Malata CM. The effect of CT angiography and venous couplers on surgery duration in microvascular breast reconstruction: a single operator's experience. *Gland Surg* 2018;7(5):440-448. doi: 10.21037/gs.2018.07.11